Development and Validation of WACCM-X Thermosphere and Ionosphere

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Major CESM WACCM/WACCM-X Components

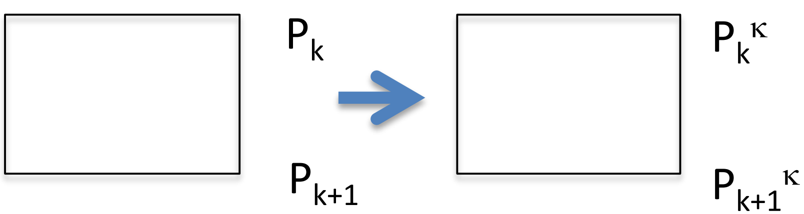
Model Framework	Chemistry	Physics	Physics	Resolution
Atmosphere component of NCAR Community Earth System Model (CESM) Extension of the NCAR Community Atmosphere Model (CAM) Finite Volume Dynamical Core (modified to consider species dependent Cp, R, m) Spectral Element Dynamical Core	MOZART+ Ion Chemistry (~60+ species) Fully-interactive with dynamics.	Long wave/short wave/EUV RRTMG IR cooling (LTE/non-LTE) Modal Aerosal CARMA Convection, precip., and cloud param. Parameterized GW Major/minor species diffusion (+UBC) Molecular viscosity and thermal conductivity (+UBC) Species dependent Cp, R, m.	Parameterized electric field at high, mid, low latitudes. IGRF geomagnetic field. Auroral processes, ion drag and Joule heating Ion/electron energy equations Ambipolar diffusion Ion/electron transport Ionospheric dynamo Coupling with plasmasphere/magnetosphere	Horizontal: 1.9° x 2.5° (lat x lon configurable as needed) Vertical: 66 levels (0-140km) 81/126 levels 0-~600km Mesoscale-resolving version:0.25 deg/0.1 scale height.

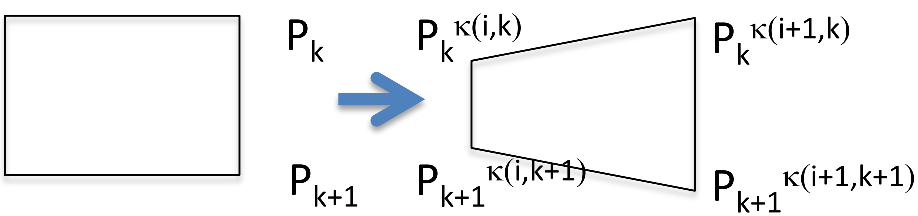
What's New In CESM2/WACCM-X

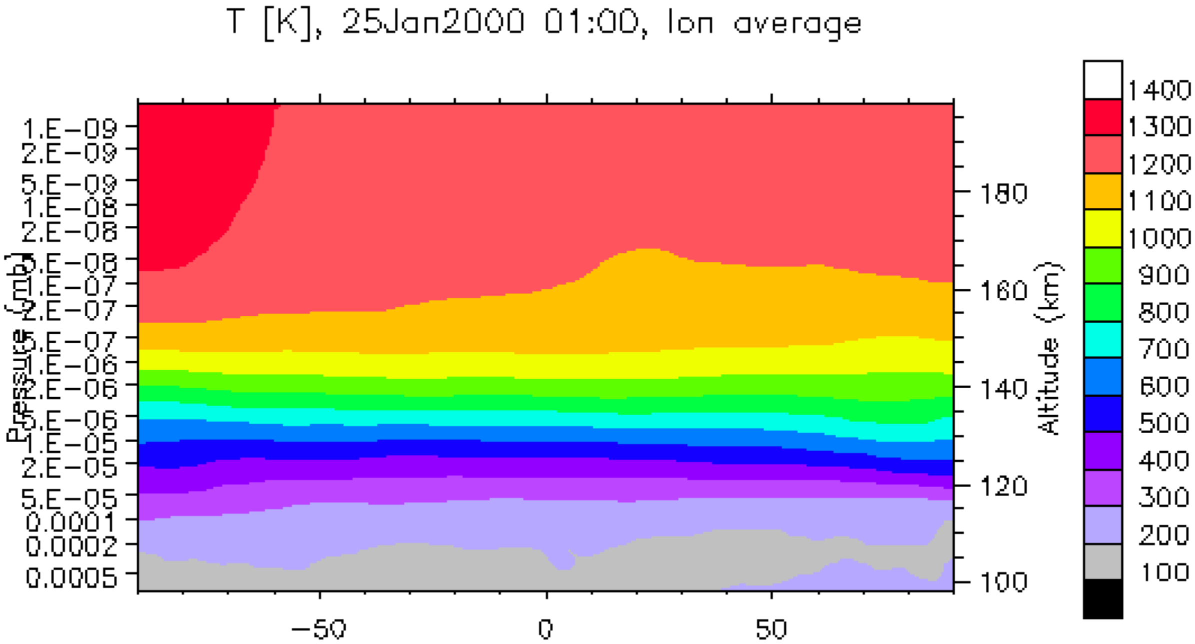
- Interactive Ionosphere Modules
  - Interactive electric wind dynamo.
  - F region O+ transport.
  - Time dependent Te/Ti solver, and thermal electron heating of neutral atmosphere.
  - $O^+(^2P)$ and $O^+(^2D)$ included in ion chemistry and energetics.
- Thermosphere Modules
  - Ability to take flare time EUV input.
  - $O(^3P)$ cooling.
  - H escape flux parameterization implemented.
  - Helium being added as a minor species.
- Dynamic core: Species dependent specific heats and gas constant.
- Model domain extended to 4×10^{-10} hPa, with ¼ scale height resolution.
- Reduced divergence damping improves tides.
- WACCM-X with specified dynamics.
- Data Assimilation with WACCM/WACCM-X DART.

Adapting FV Dycore for Variable Species: Momentum Equations

- Treatment of pressure gradients in horizontal momentum equations.
  - Standard FV core uses Exner function (p^κ) as the vertical coordinate for the contour integral of the pressure gradient terms ($\kappa = R/C_p$).
  - When κ is a variable, Exner function is not a constant on an isobaric surface, so can't be used as a vertical coordinate.
  - Use pressure or log-pressure instead for computing the contour integral (latter has been used in our implementation).

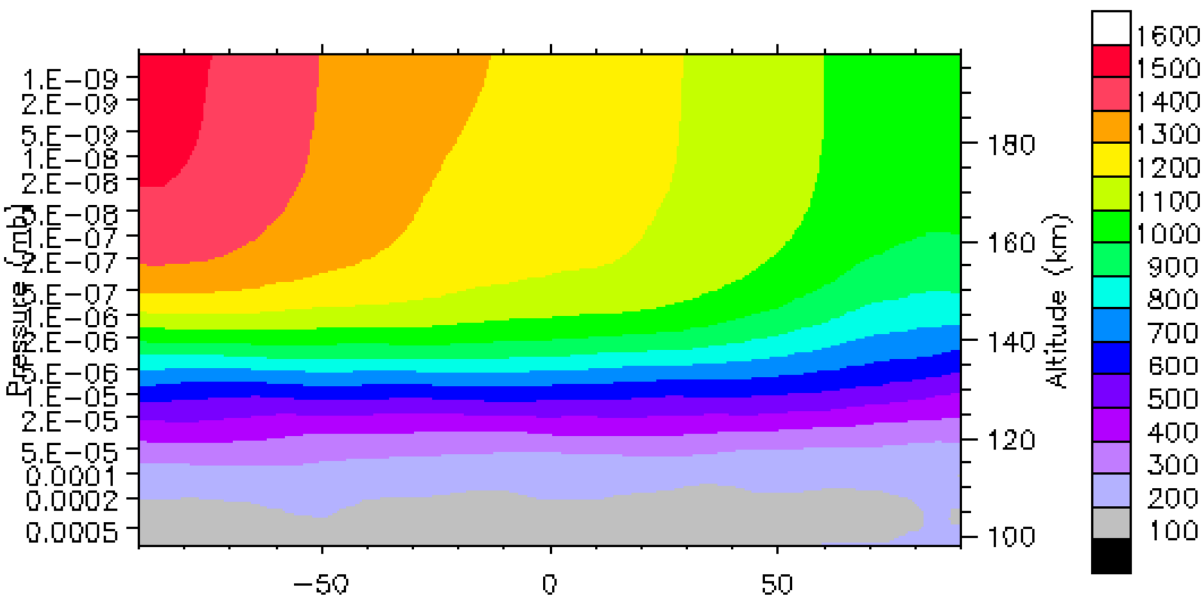






p^{κ} used as vertical coordinate (standard FV dycore)

Tmax = 1372 K



ln(p) used as vertical coordinate (modified FV dycore)

Tmax = 1523 K

Horizontal winds and divergence are solved incorrectly (and often become too strong) with the standard formulation. Causes excessive upwelling in the summer and downwelling in the winter.

Adapting FV Dycore for Variable Species: Thermal Equation and Hydrostatic Equation

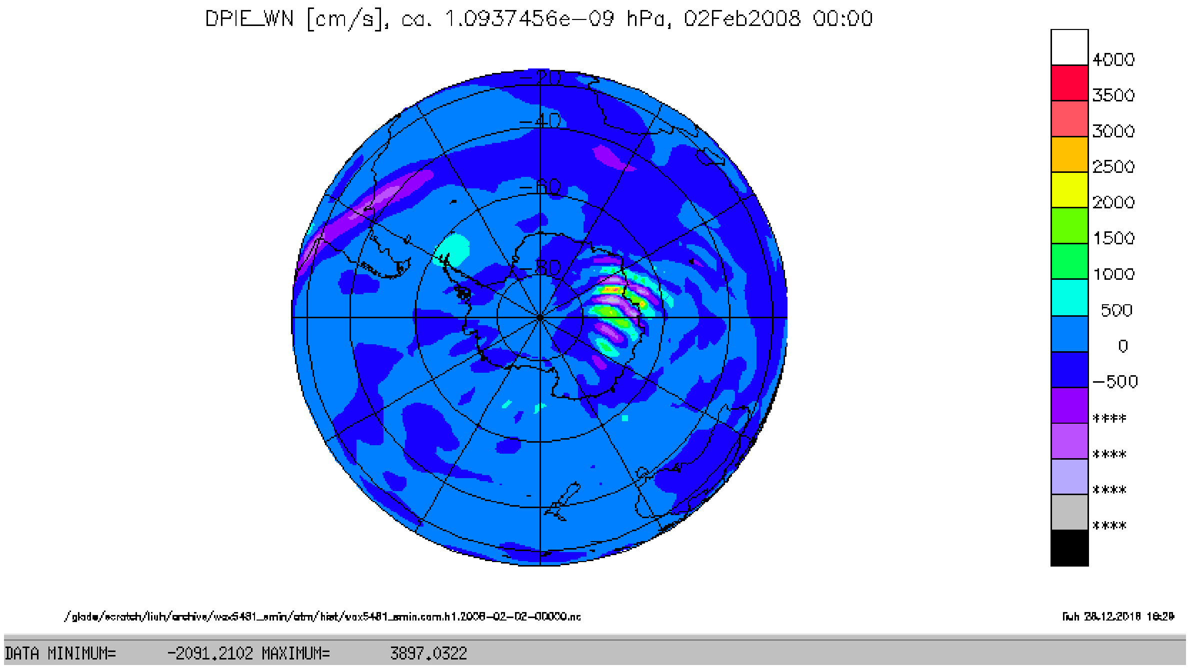
- Thermal equation using potential temperature:

$$\frac{\partial(\Theta\delta p)}{\partial t}+\nabla_H\cdot(\vec{V}_H\Theta\delta p)=\boxed{\Theta\ln(p/p_0)(\frac{\partial(\kappa\delta p)}{\partial t}+\nabla_H\cdot(\vec{V}_H\kappa\delta p))}$$

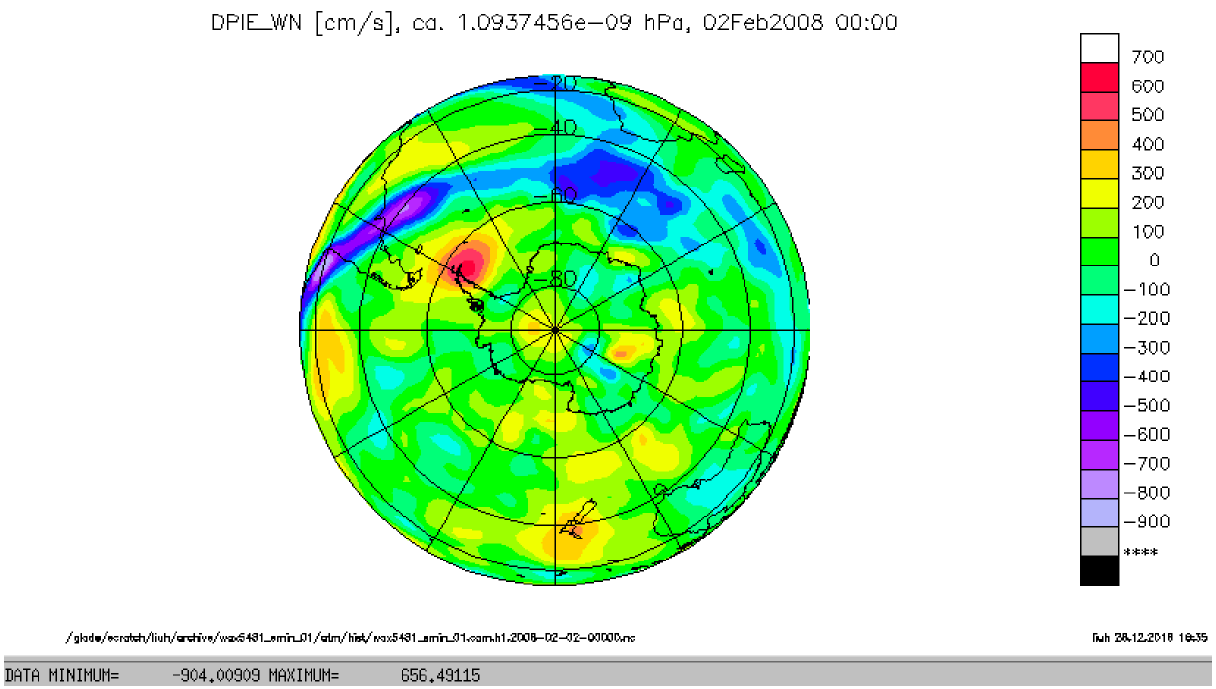
advection of κ should be considered.

- Hydrostatic relation $\delta\phi=C_p\Theta\delta(p^\kappa)$ is used in rebuilding geopotential. This is correct if κ is a constant, but yields an extra term if κ is variable. Should use $\delta\phi=C_p\kappa p^\kappa\Theta\delta(\ln p)$.

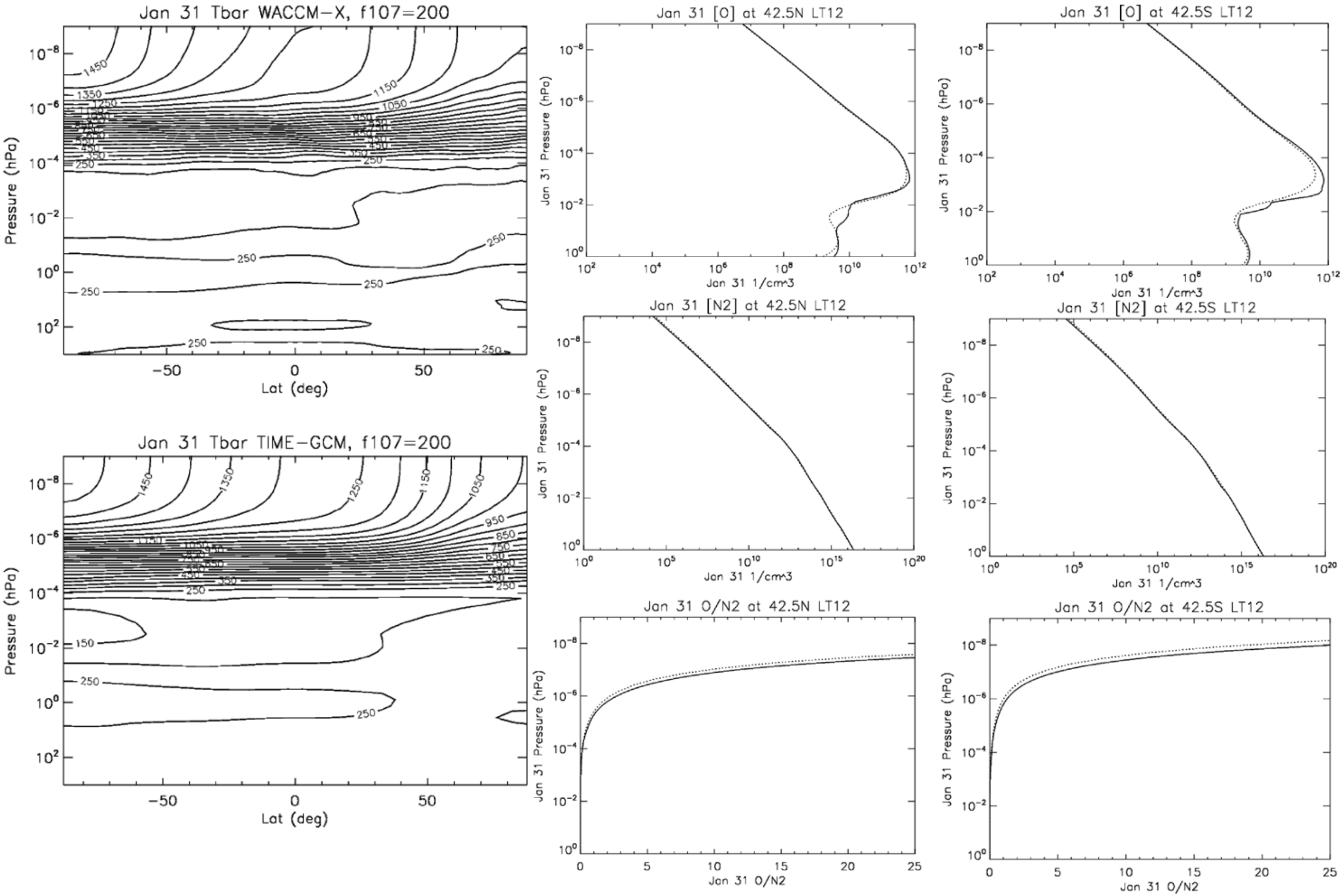
Without advecting κ



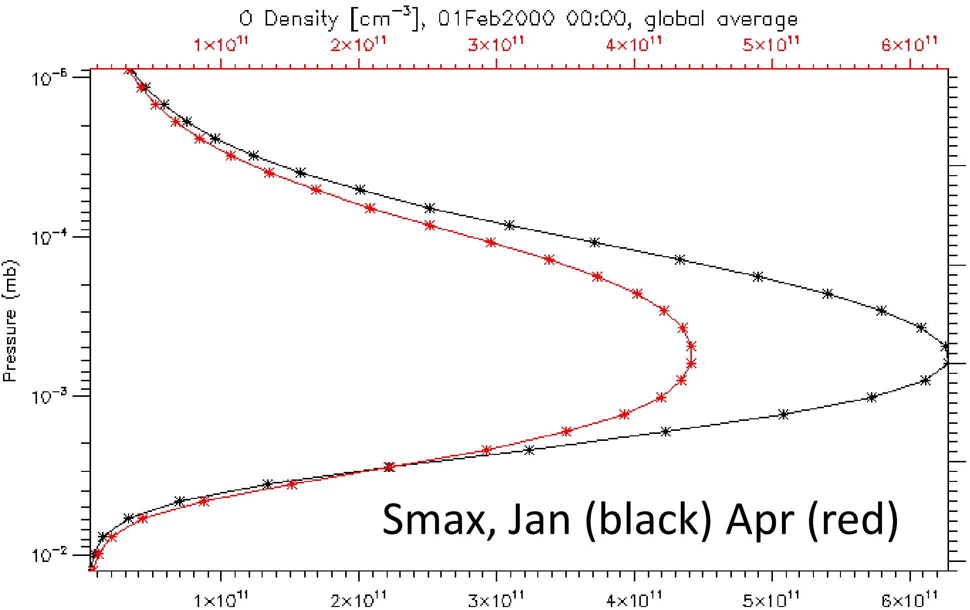
With κ advection

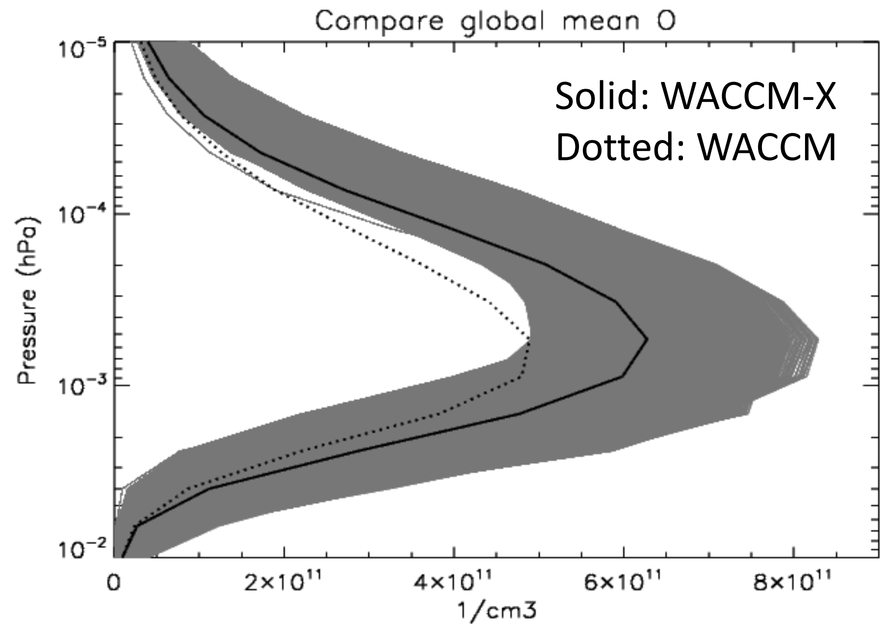


T and O, N2 (O/N2): WACCM-X and TIME-GCM



O Peak in MLT

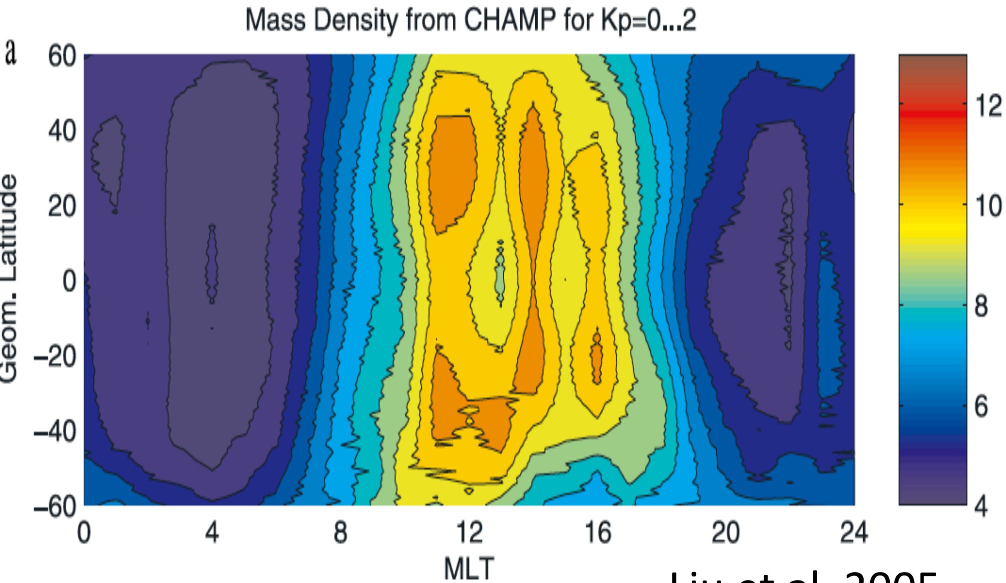




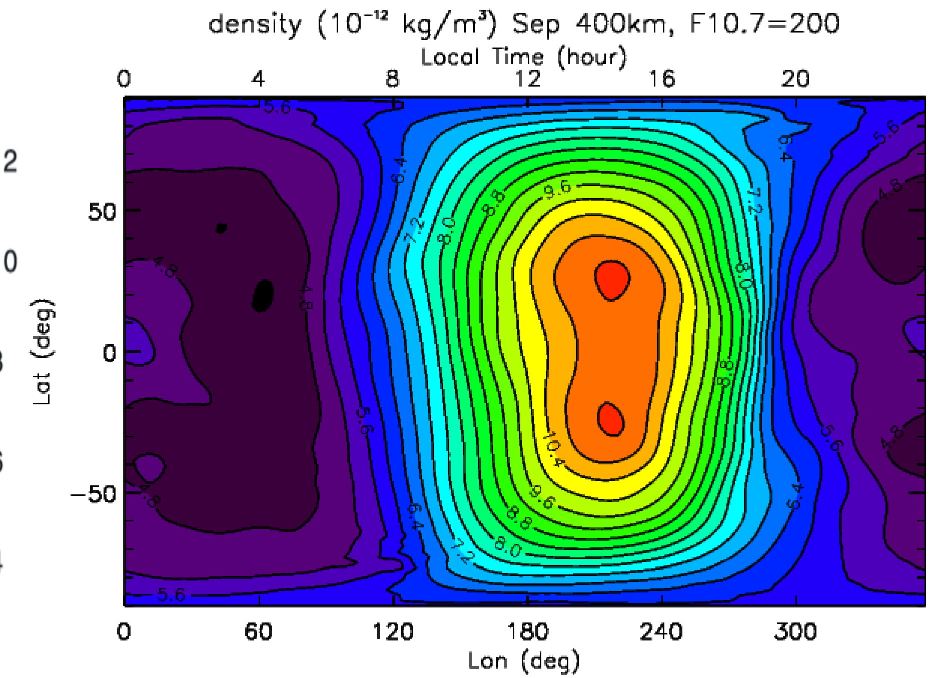
	Pressure			
	0.01 hPa	0.003 hPa	0.001 hPa	0.0004 hPa ~~0.004 hPa~~
Mean altitude (km)	79.2	86.2	92.7	97.9
Day O density (cm $^{-3}$)	1.58 e+10	1.43 e+11	6.22 e+11	7.66 e+11
Night O density (cm $^{-3}$)	5.44 e+09	2.23 e+11	6.56 e+11	5.58 e+11

Smith et al., 2010

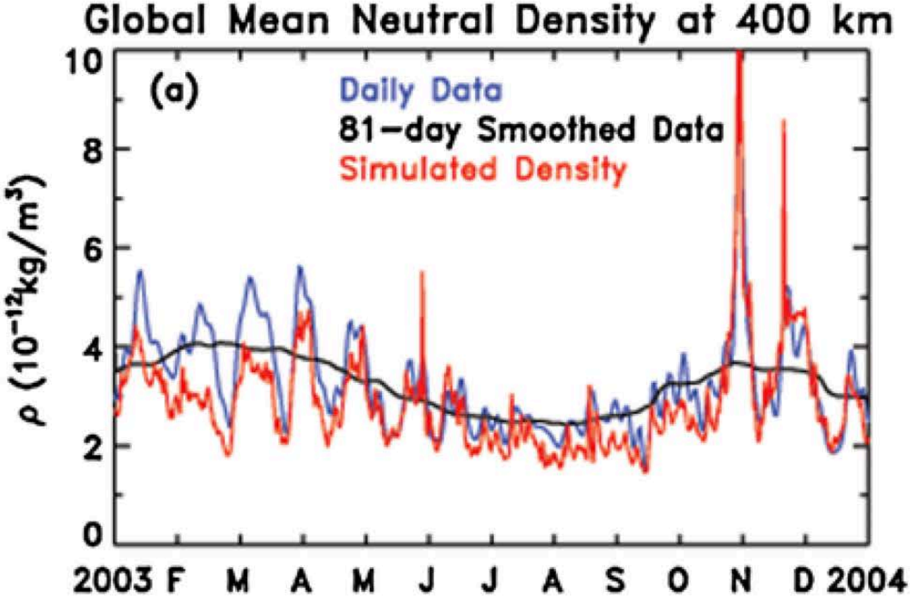
Thermospheric Density at 400km

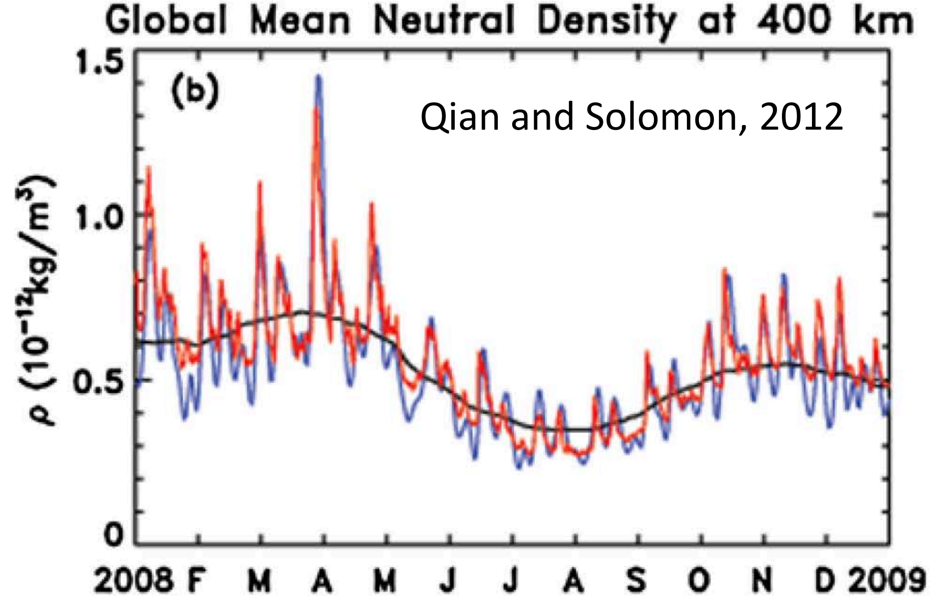


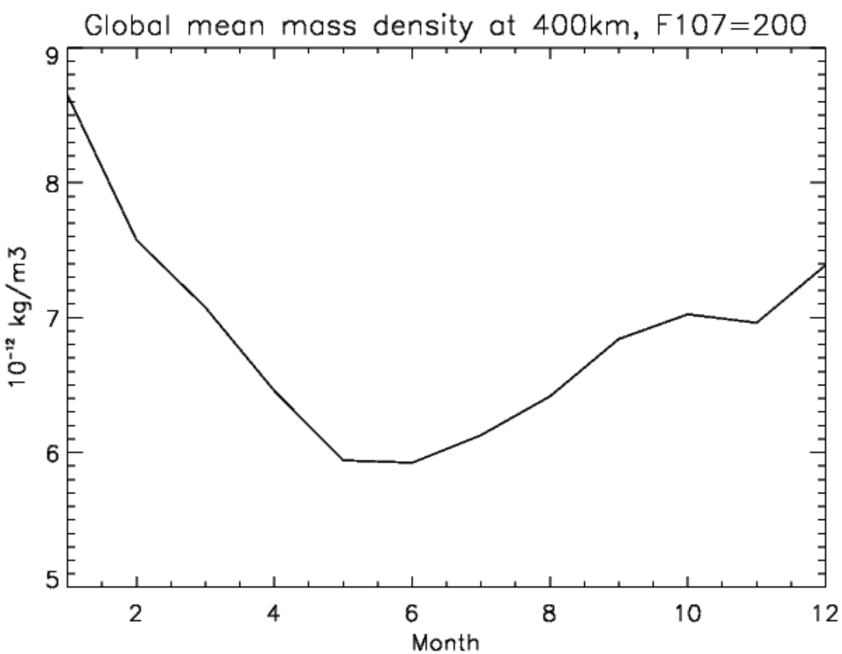
Liu et al. 2005

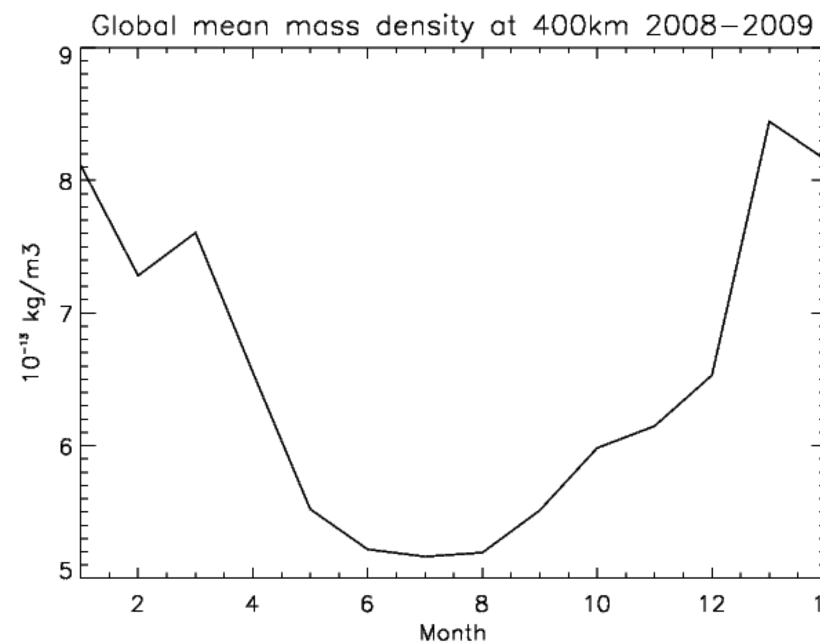


Annual Variation

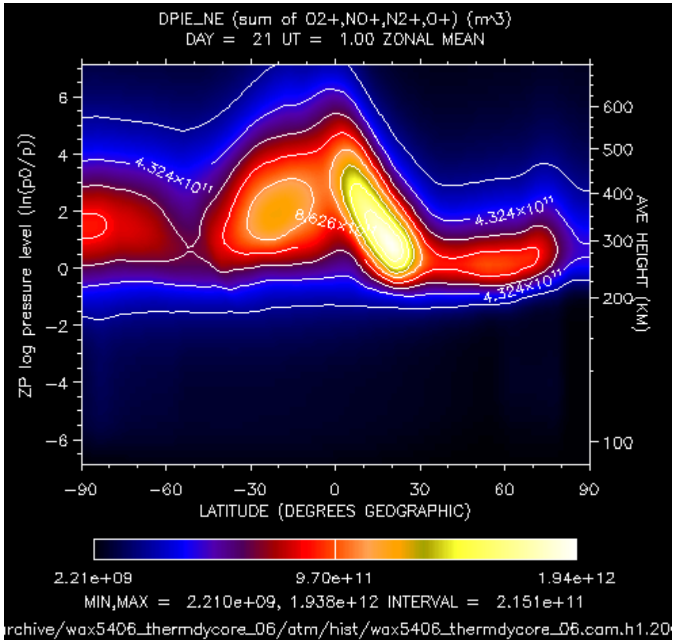






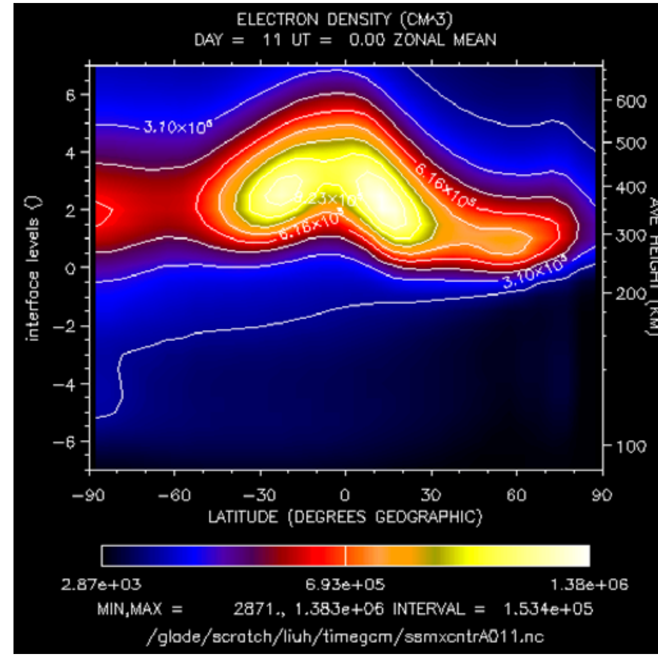


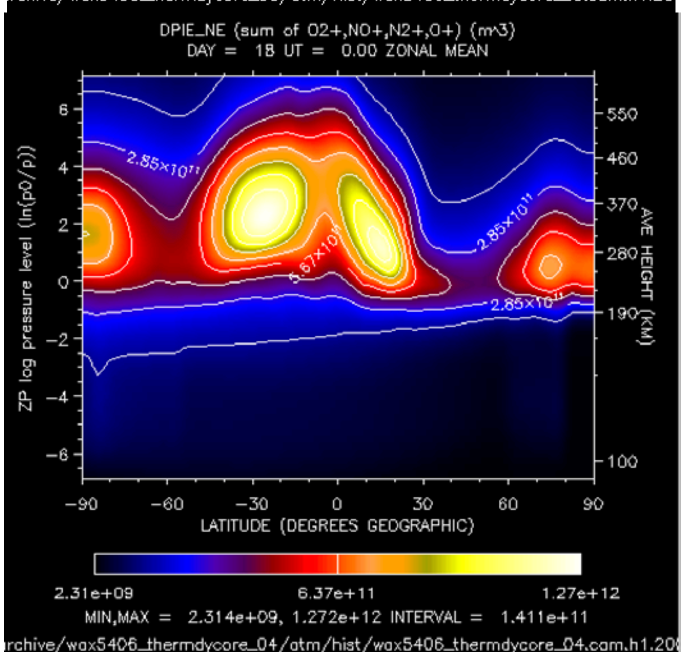
O+ in WACCM-X and TIME-GCM



WACCM-X with new dycore

TIME-GCM

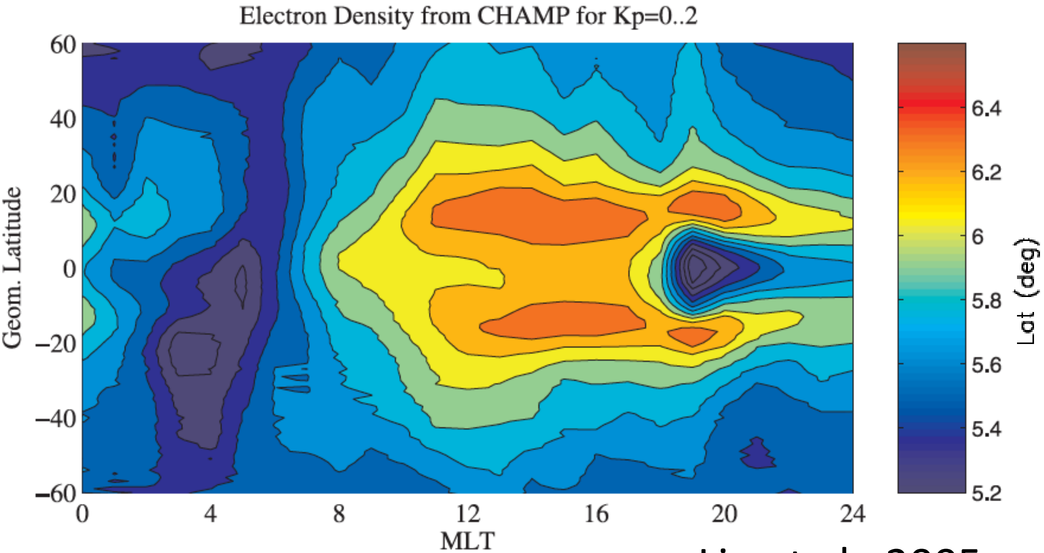




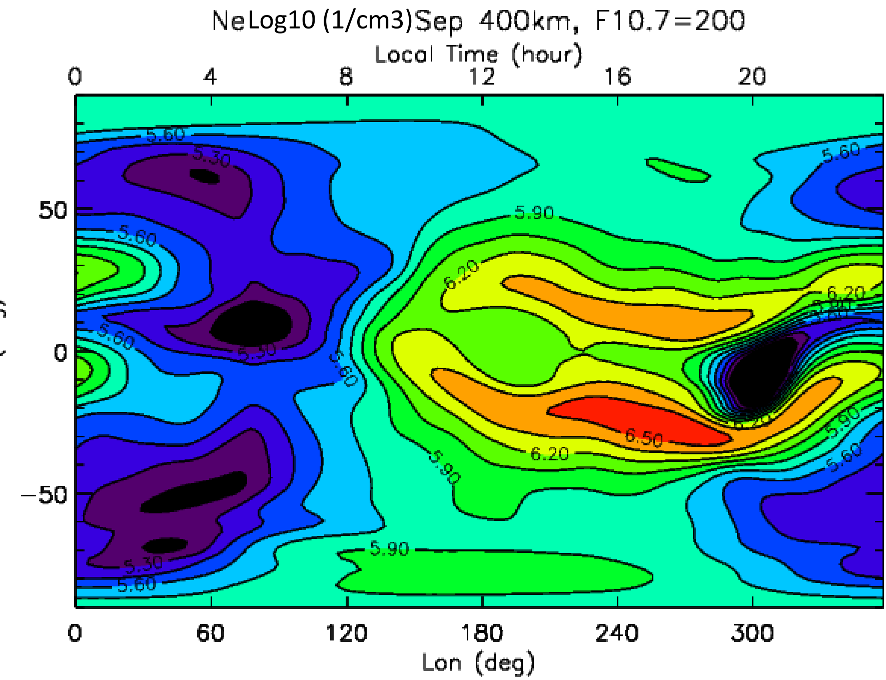
WACCM-X with old dycore

The spurious accumulation of O+ at high laitutdes is gone after the dycore fix.

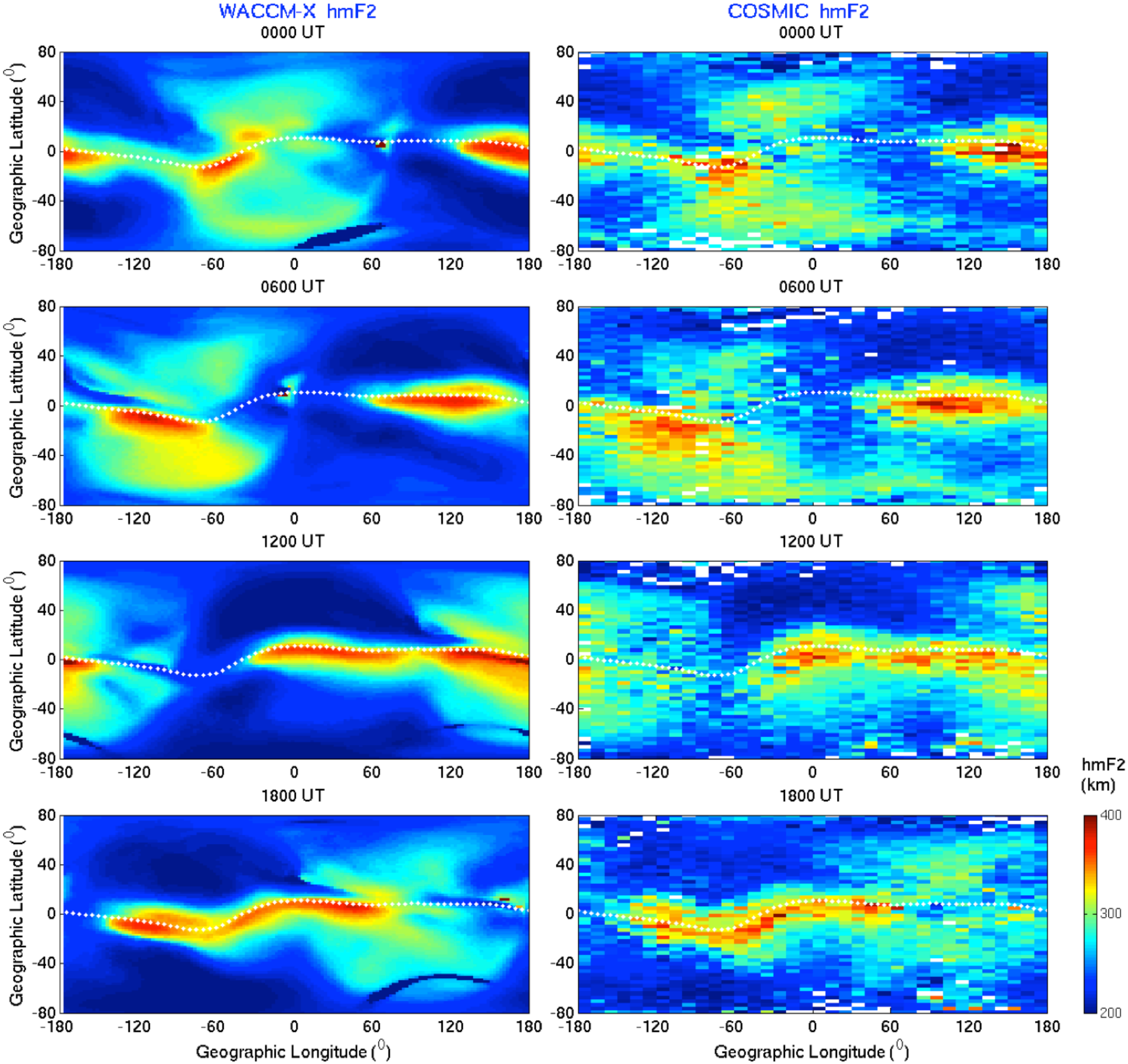
Electron Density at 400km



Liu et al., 2005

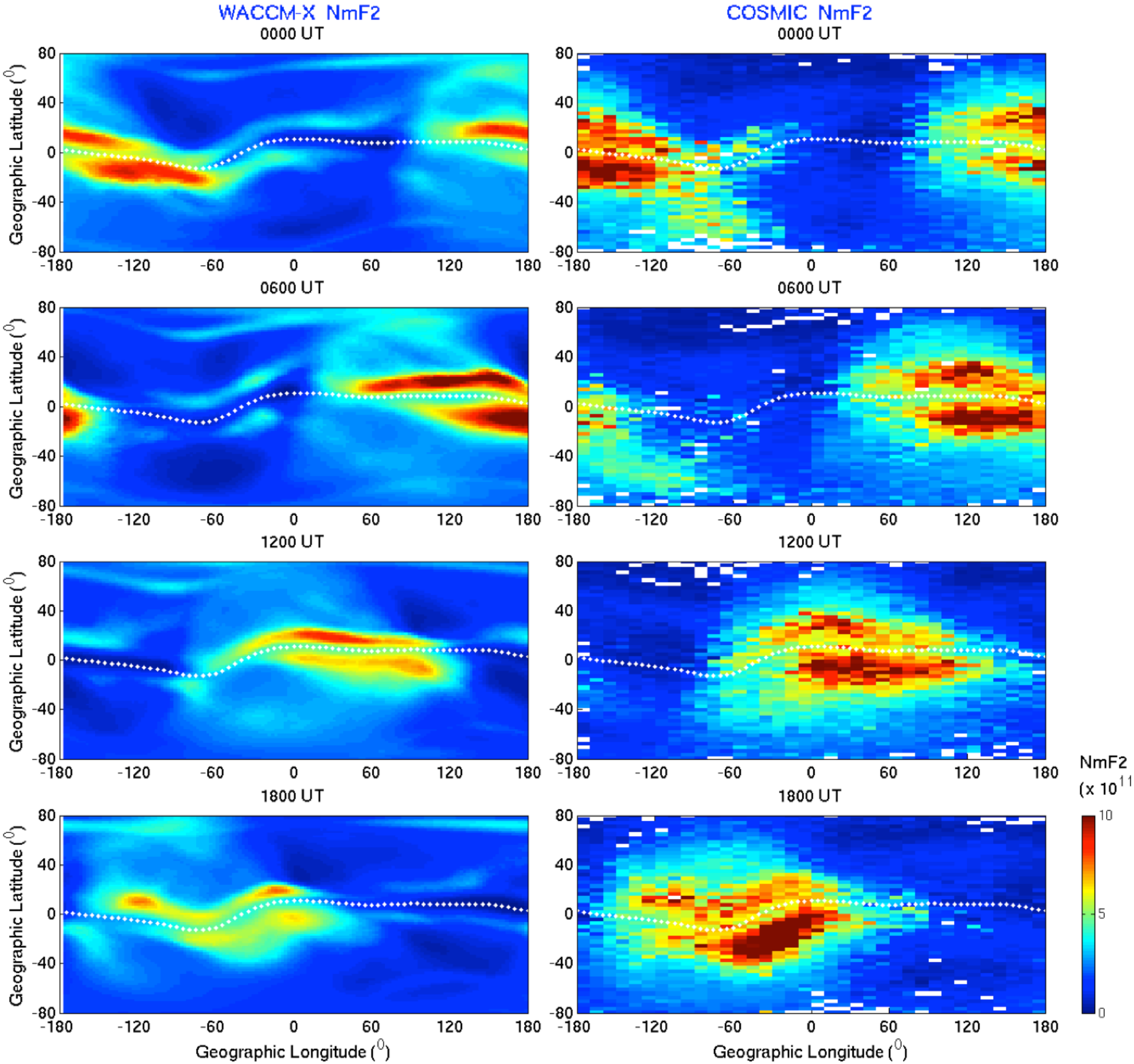


Comparison with COSMIC 2008 Jan-Feb



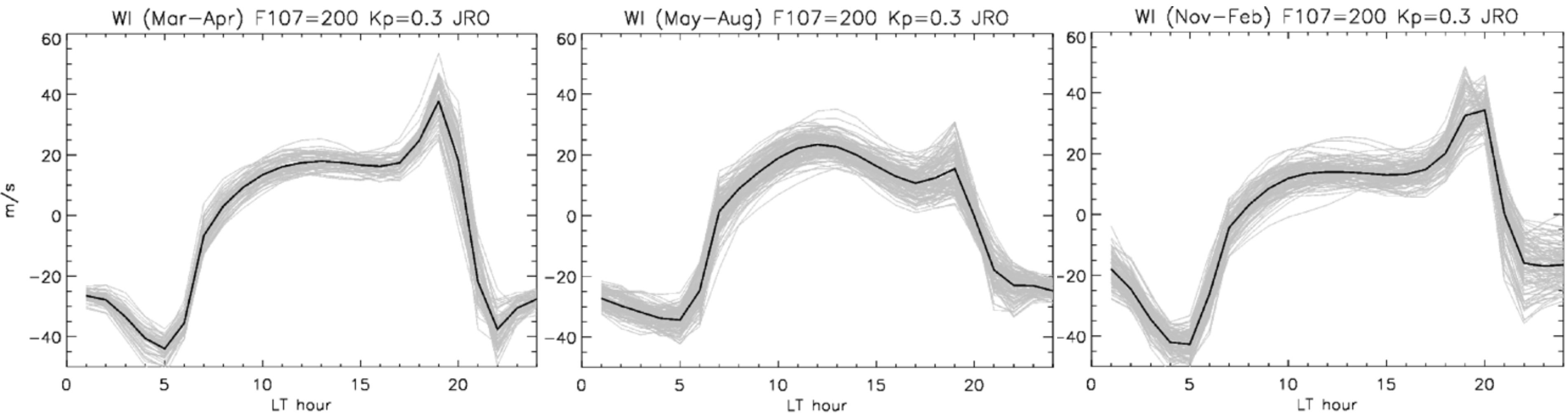
Courtesy of Jing Liu

Comparison with COSMIC 2008 Jan-Feb

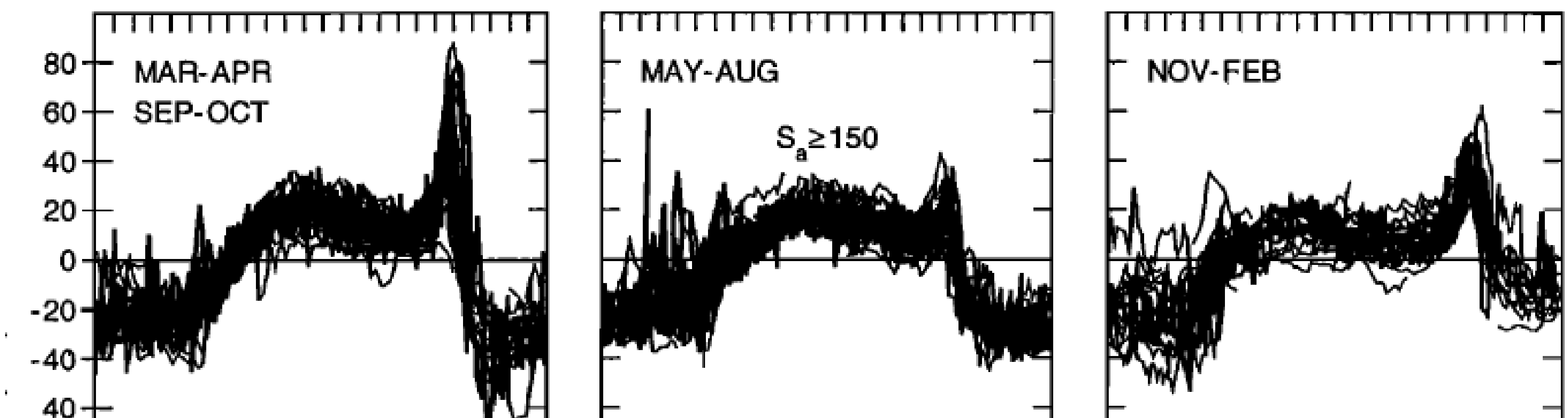


Courtesy of Jing Liu

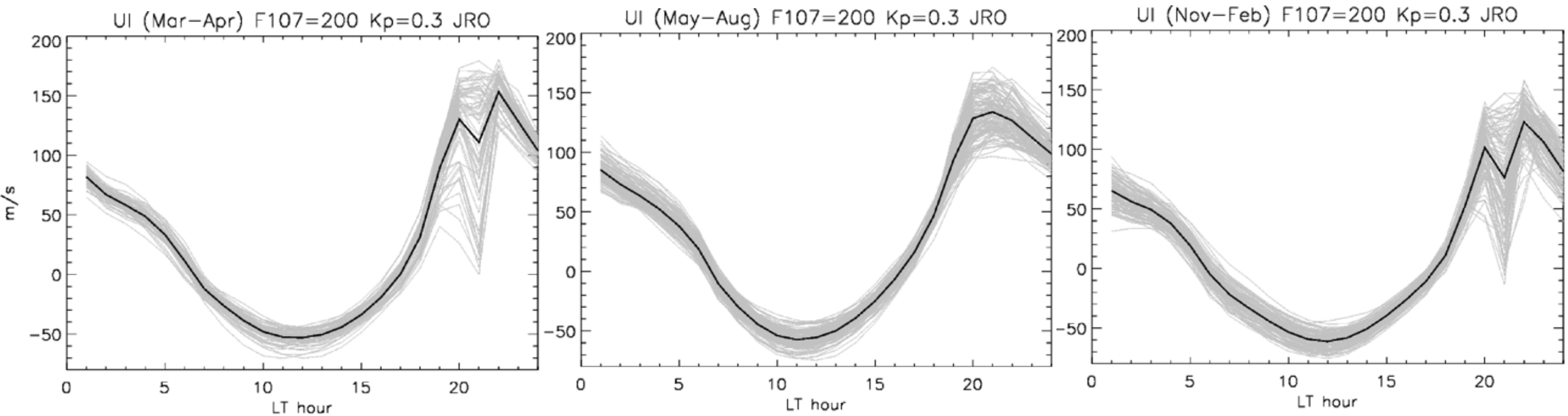
Vertical ExB Drift: Comparison with Smax Climatology



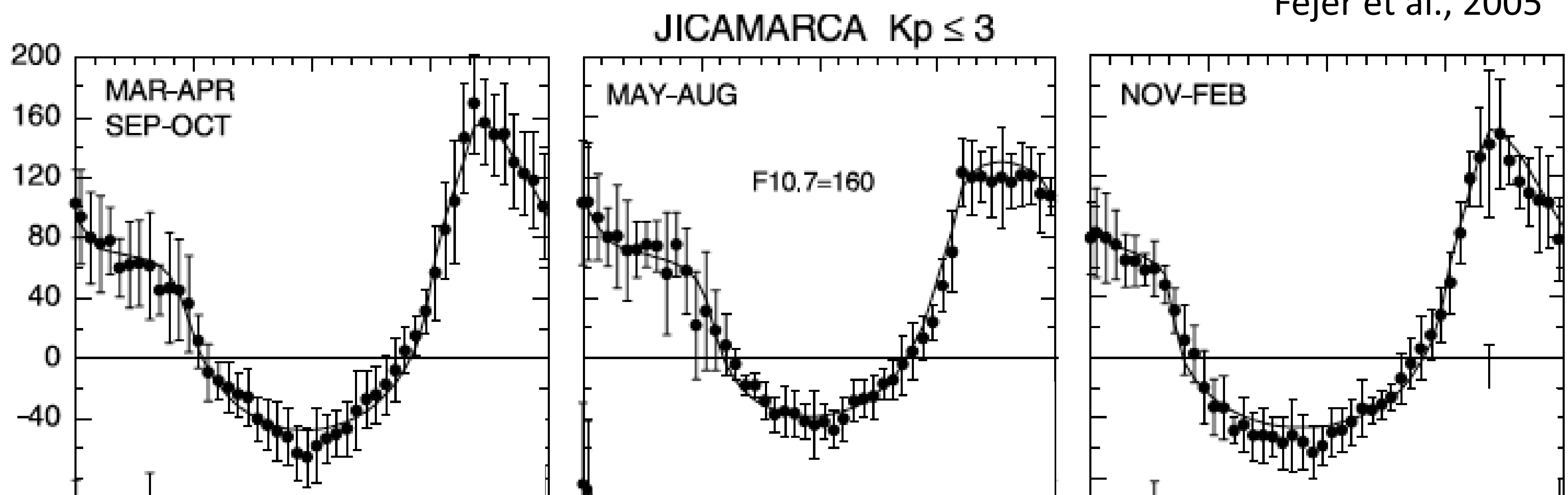
Scherliess and Fejer, 1999



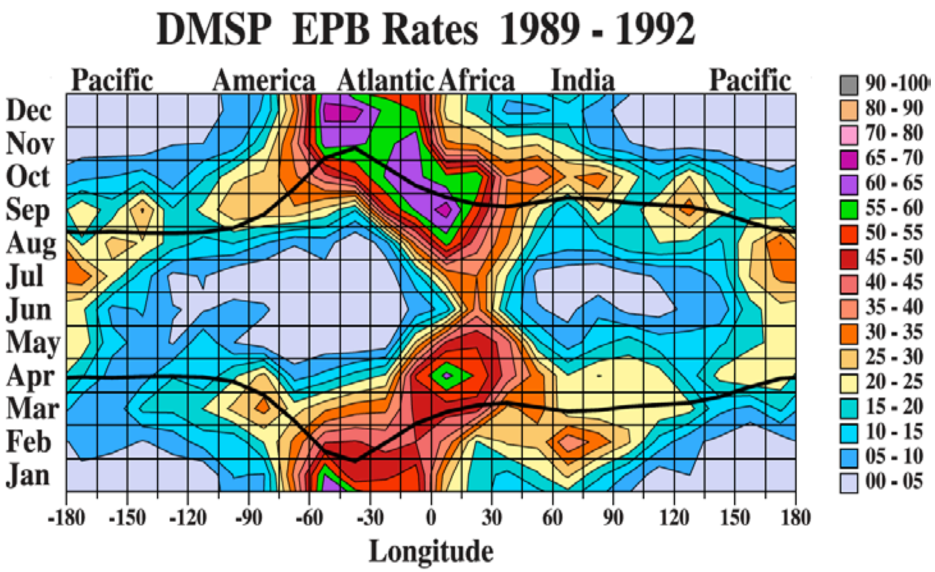
Zonal ExB Drift: Comparison with Smax Climatology



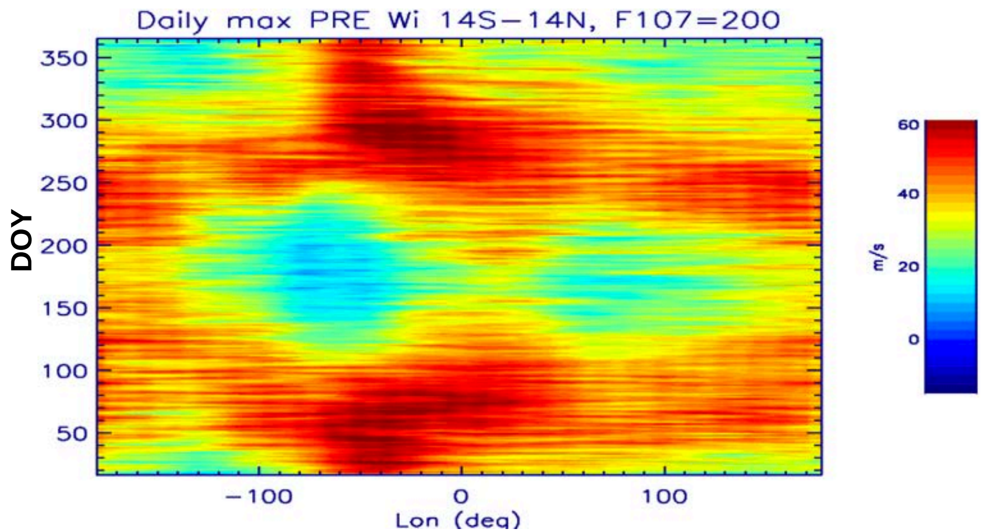
Fejer et al., 2005



WACCM-X Ionosphere: PRE Variability

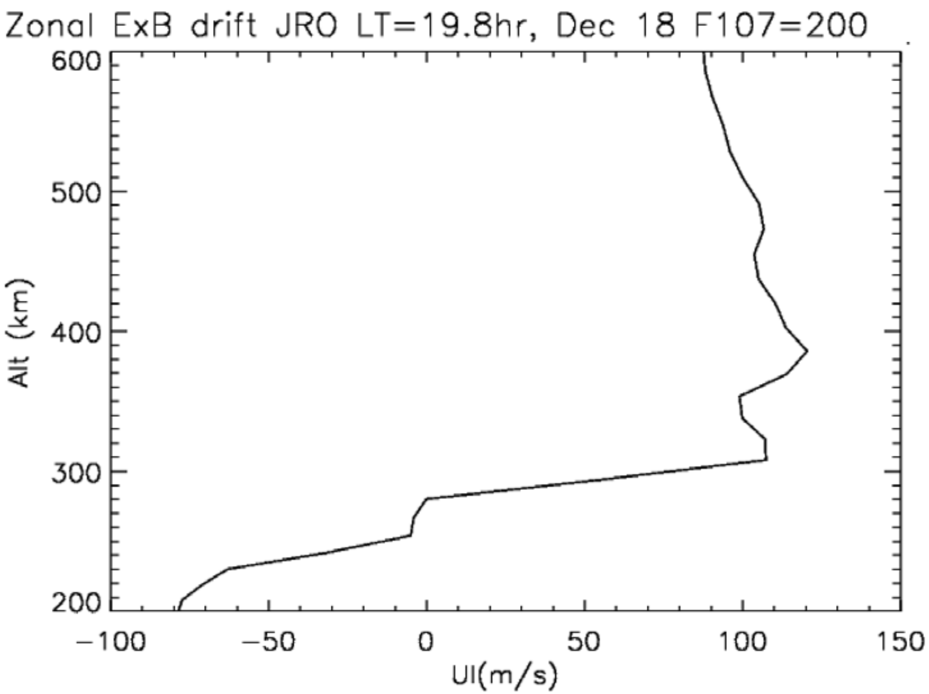


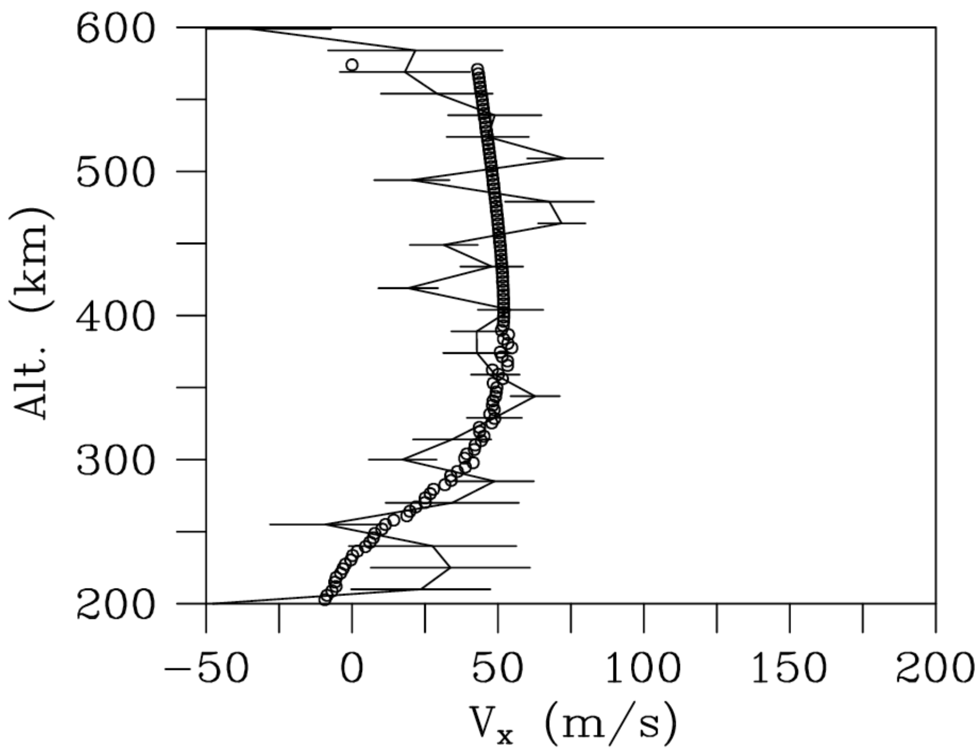
Gentile et al., 2006



WACCM-X Solar Max: Constant F107 and Kp

Vertical Profile of Zonal Drift: Smax

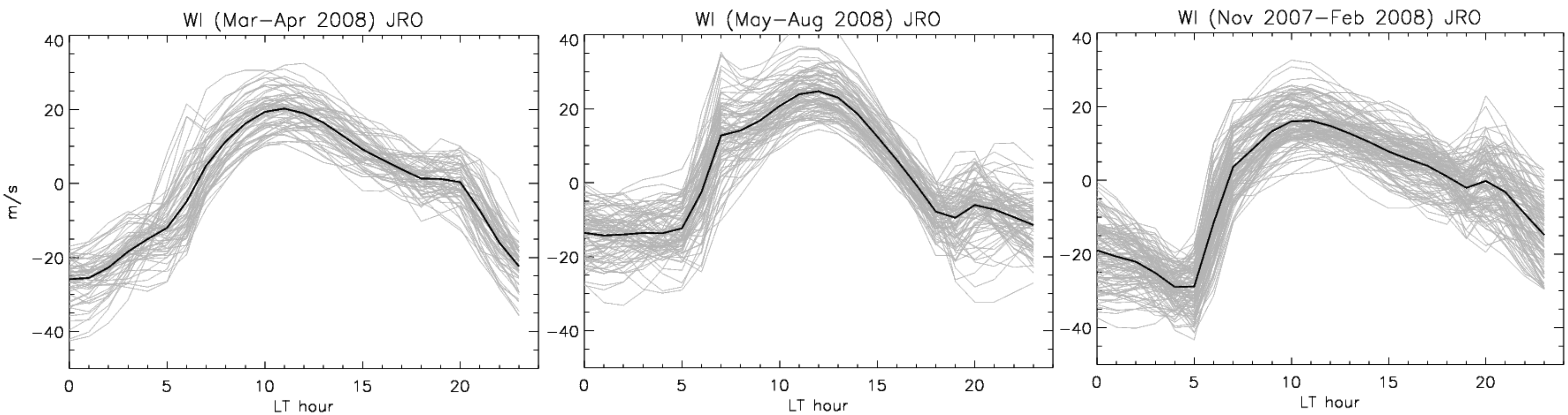




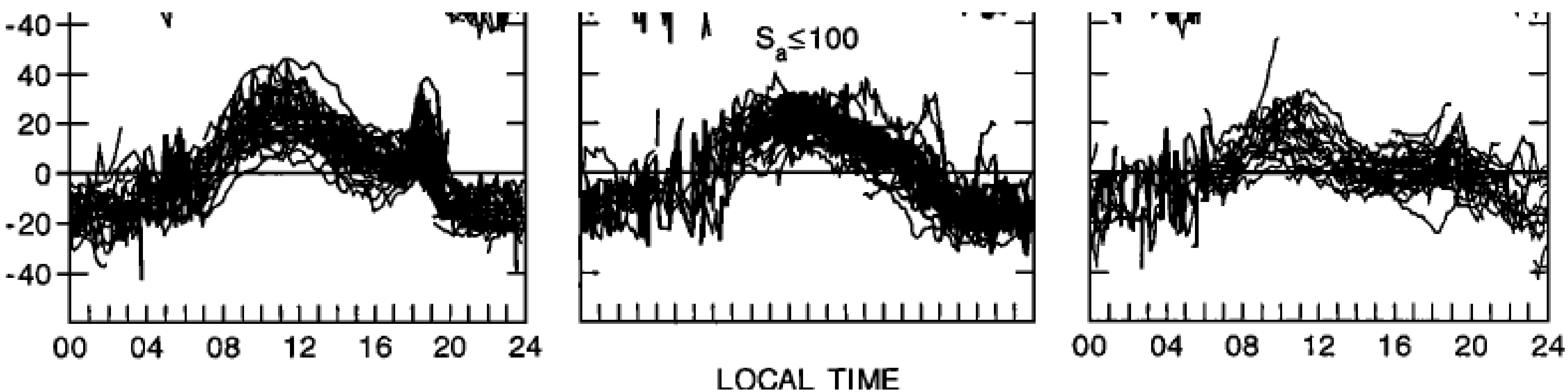
2014/12/18

Hysell et al. (2015)

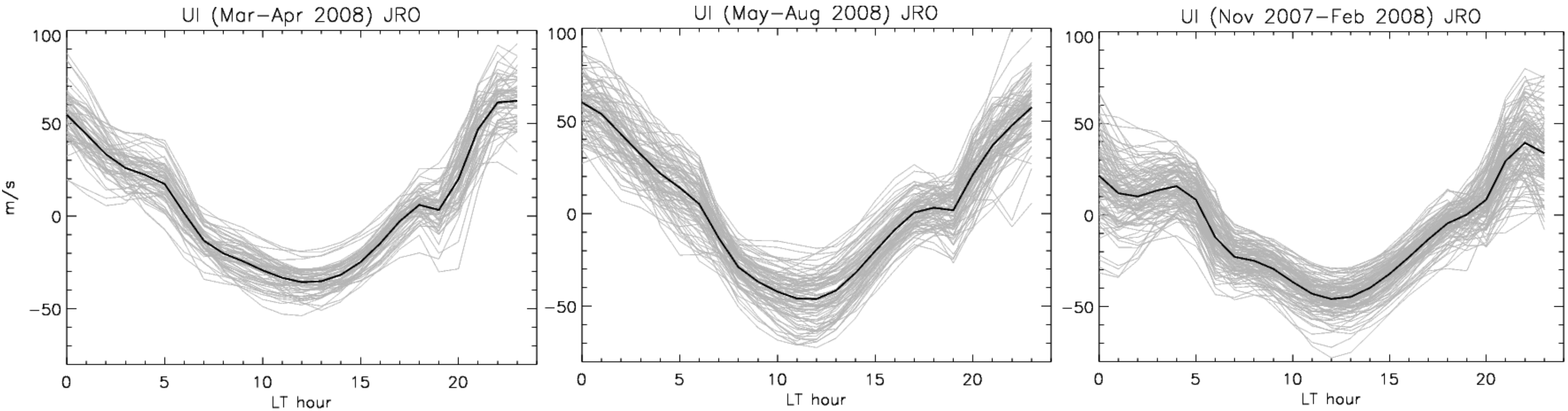
Vertical ExB Drift: Comparison with Smin Climatology



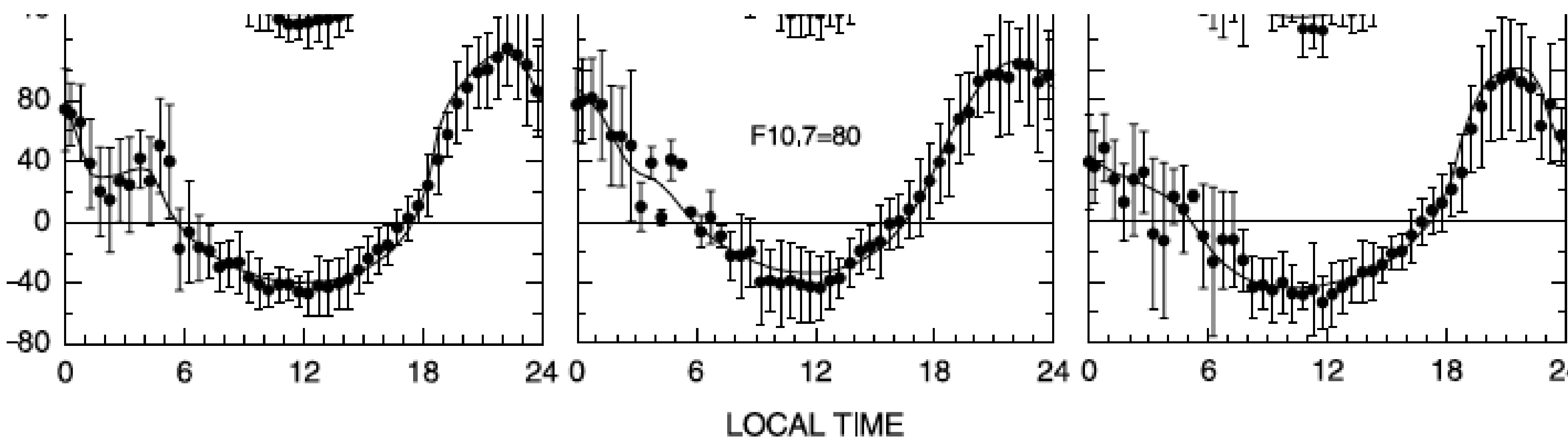
Scherliess and Fejer, 1999



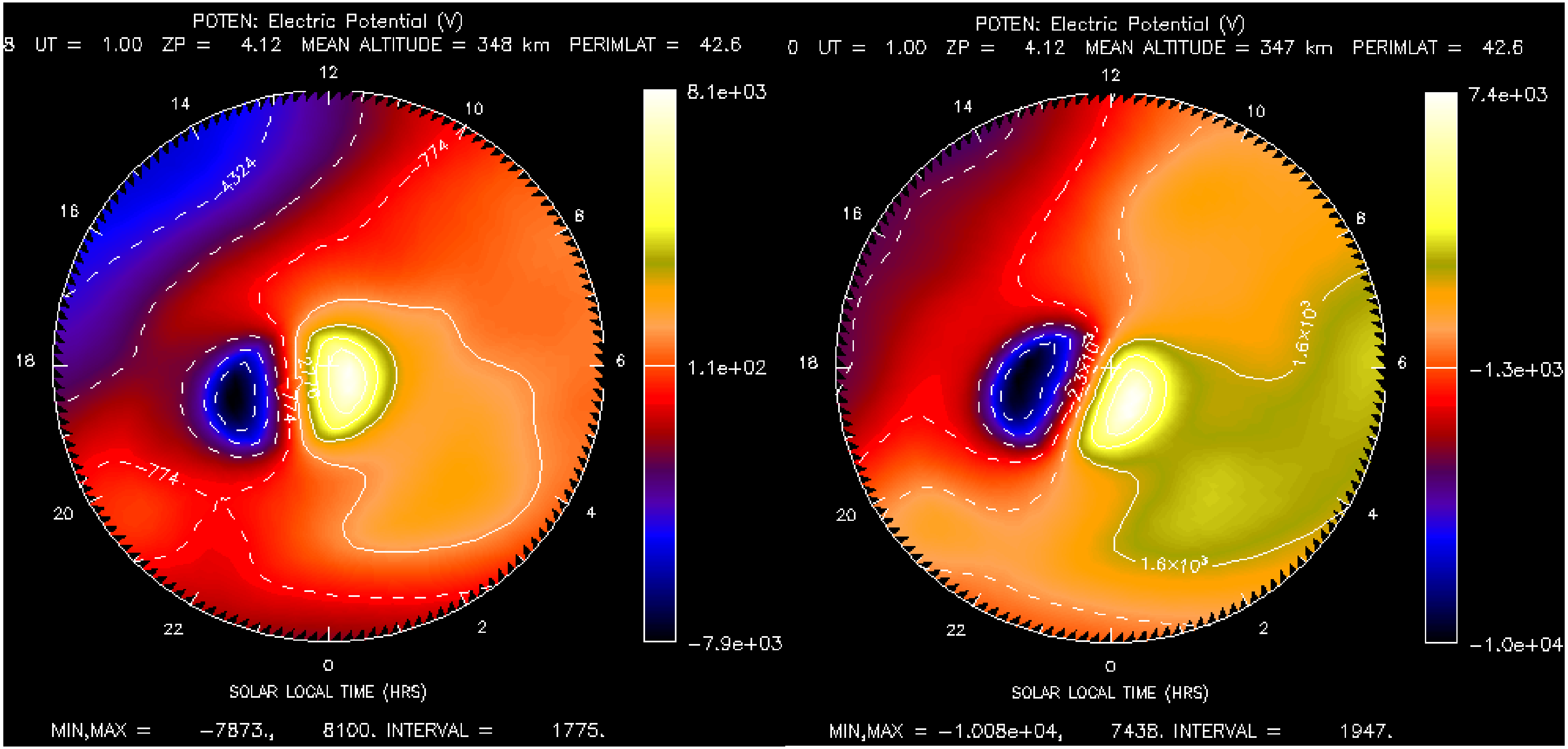
Zonal ExB Drift: Comparison with Smin Climatology



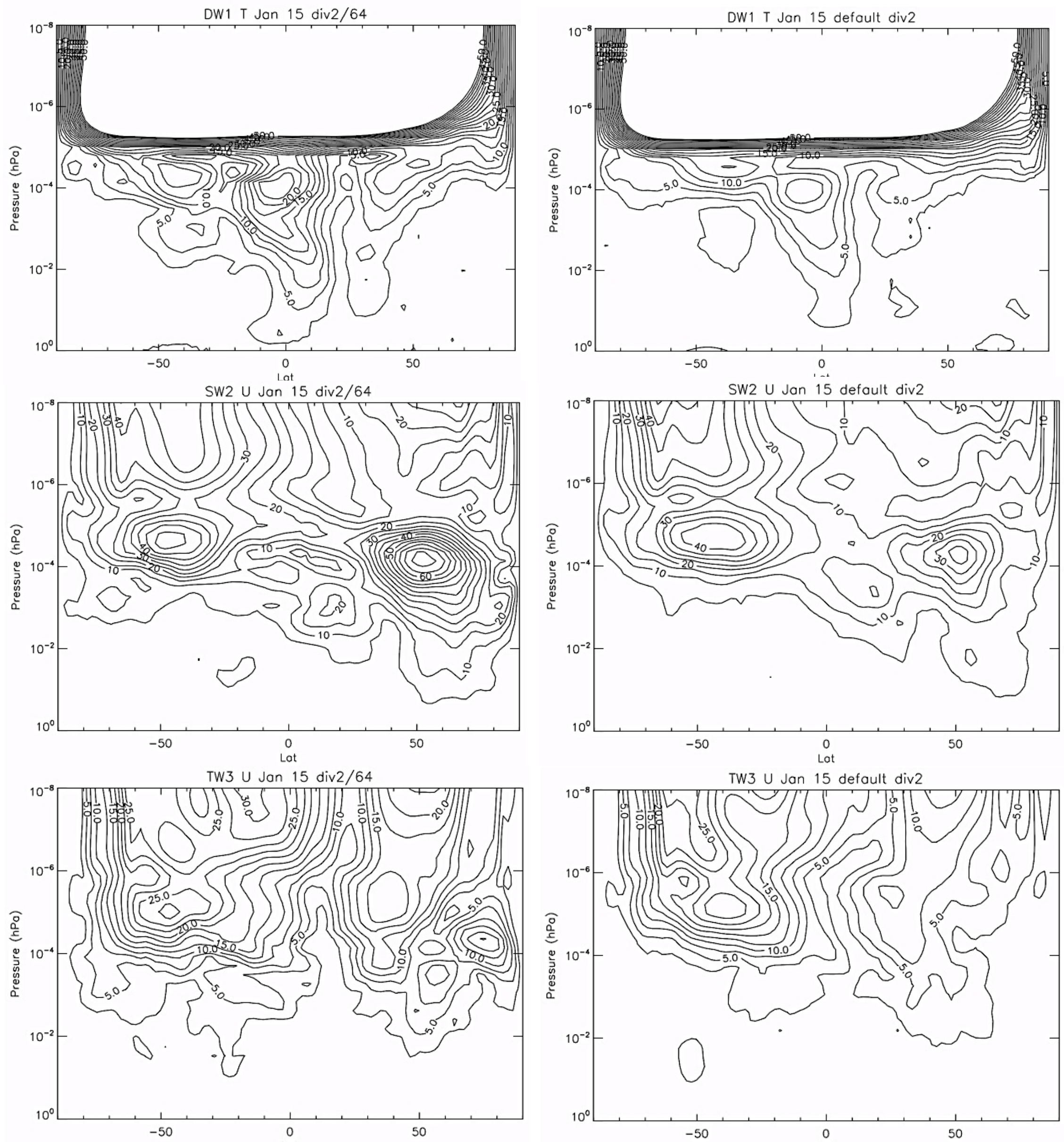
Fejer et al., 2005



High Latitude Convection Pattern: Heelis



WACCM-X Tides



Take Home Message…

- The WACCM-X thermosphere and ionosphere compare well with observations/climatology.
- Try it out when it's released (within the next few months)

Current Development

- Implementation and testing of Helium.
- Prepare for CESM2.0 release (scheduled for December 2016), which will include WACCM-X with the aforementioned features.
- WACCM-X/AMIE.
- WACCM-X Data Assimilation (DART).